MAXIMUM INTEGRATED CIRCUIT UTILIZATION THROUGH MIXING COMPATIBLE LOGIC FAMILIES

by Robert Ricks

I INTRODUCTION

Although a wide variety of integrated circuits is on the market today—T^2L, DCTL, RTL, CTL, etc. —the complaint is often heard that no one family can meet the rigid specifications of a particular digital system. However, by carefully evaluating and comparing the electrical characteristics of two families, it is often possible to marry elements from both. For example, a requirement for maximum speed and minimum power is difficult and costly to meet with one family, but hybrids can be used which combine Fairchild high-speed Micrologic® integrated circuits and low-power, milliwatt Micrologic® integrated circuits (μL® MWμL) that do meet these requirements. In fact, such hybrid μL-MWμL combinations not only have the best features of both families, but in some respects are actually superior to comparable single-family circuits.[1] One μL inverter, for example, can drive five other μL inverters with a power dissipation of 15 mW and a propagation delay (t_{pd}) of 10 nsec. One MWμL inverter will drive four other MWμL inverters with a power dissipation of 2 mW and a t_{pd} of 25 nsec. However, one μL inverter can drive 16 MWμL inverters with a power dissipation of 15 mW and a t_{pd} of 10 nsec, or, if power is the critical specification, one MWμL inverter can drive one μL and one MWμL inverter with a power dissipation of 2 mW and a t_{pd} of 25 nsec. Table I compares power, speed, and fan-out for the two families separately and in combination.

Table I

COMPARISON OF INVERTERS
(V_{CC} = 3.6 volts[2])

Family	Possible No. of Loads	Speed (nsec)	Power (mW/node)
μL	5 μL or 16 MWμL	10	15
MWμL	4 MWμL or 1 μL plus 1 MWμL	25	2

This article reviews the input-output V-I characteristics of both families, explains the loading rules for mixed MWμL and μL systems, and describes two applications illustrating the drive capability of mixed systems.

II INPUT-OUTPUT V-I CHARACTERISTICS

Figure 1 is a graph of input base current, I_{IN}, versus input base-to-emitter voltage, V_{IN}, for the μL and MWμL families, and Fig. 2 shows transfer characteristics, i.e., output collector voltage, V_{OUT}, versus V_{IN} for the two families. The transfer characteristics for the two families are similar, but the I_{IN} - V_{IN} curves differ because of the disparity in base resistor values (these values and those of the collector resistors in the two families are compared in Table II). Note that all units are turned on when V_{IN} equals 0.8 volt and that at this voltage I_{IN} is 0.1 mA for MWμL and 0.3 mA for μL.

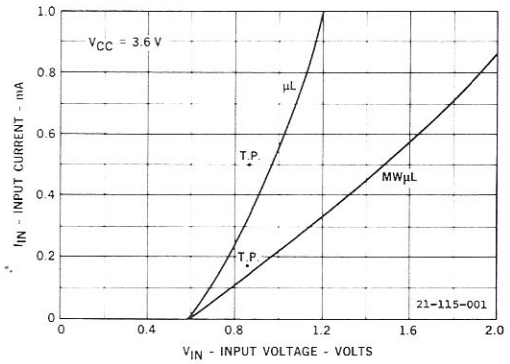

FIG. 1. Input base current vs. input voltage.

[1] An industrial μL family has been developed which offers the advantages of high speed and low power dissipation at a price of only $1.32 per gate. Two such gates are supplied in a single package including interconnections for only $2.65 in 100 lot quantities.

[2] A supply voltage of 3.6 volts was selected for the industrial family in order to obtain the maximum fan-in and fan-out for industrial requirements. Normally, military μL and MWμL families operate at 3 volts.

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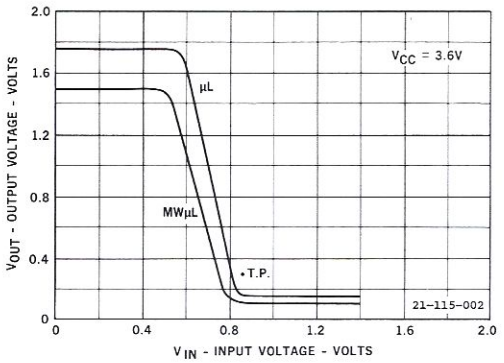

FIG. 2. Output collector voltage vs. input voltage.

Table II

COLLECTOR AND BASE RESISTANCE VALUES

Family	Collector Resistance (Ohms)	Base Resistance (Ohms)
μL	≈ 640	≈ 450
MWμL	≈ 3,600	≈ 1,500

In order to mix the two families we must know not only the input current, I_{IN}, required for both but also the output current, I_{OUT}, at the collectors of both when the base of the subsequent stage is at a specified V_{IN}. This information can be obtained from the graph of Fig. 3, which shows I_{OUT} versus V_{IN} for the subsequent stage. Like the I_{IN} - V_{IN} curves of Fig. 1, these plots differ because of the disparity in collector resistor values (shown in Table II). When V_{IN} is 0.8 volt (the voltage at which all units are turned on), the current, I_{OUT}, is 0.75 mA from a MWμL driving stage and 3.4 mA from a μL driving stage. These values of I_{OUT}, reduced by 30 percent to allow for power supply variations, transistor leakage, and other losses, are minimum figures for the current I_A, actually available to drive subsequent stages.

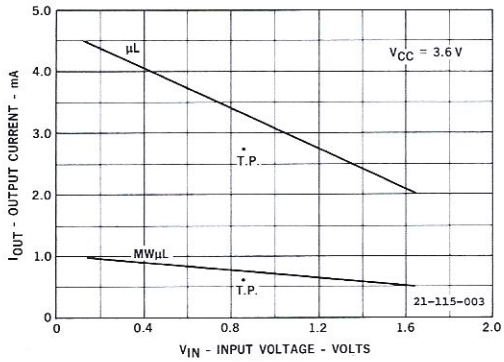

FIG. 3. Output current vs. input voltage for next stage.

Knowing I_{IN} and I_A, we can derive the loading rules for mixed μL-MWμL systems shown in Fig. 4. The numbers at the inputs and outputs of the μL and MWμL elements in this figure are normalized values of I_{IN} and I_A; the number "1" represents, as a standard of comparison, the maximum current that will be drawn by a MWμL transistor base at V_{IN} = 0.8 volt.

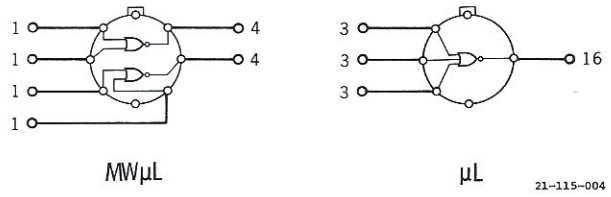

FIG. 4. Loading rules for mixed systems (V_{CC} =3.6 V).

Figure 5 plots V_{OUT} versus V_{IN} for various mixed and homogeneous systems.

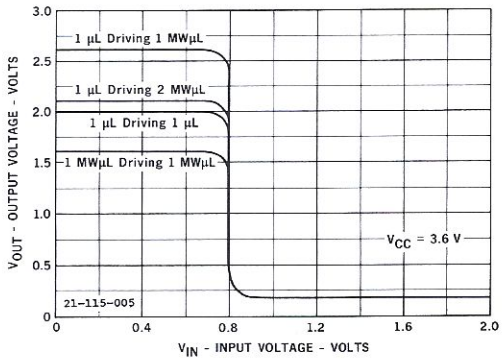

FIG. 5. Output voltage vs. input voltage.

Table III is a summary of the input and output load rating for various supply voltages.

Table III

INDUSTRIAL LOADING RULES (+15°C TO +55°C)

Supply Voltage V_{CC}	Family	Input	Output
3	μL	3	15
	MWμL	1	3
3.6	μL	3	16
	MWμL	1	4
4	μL	3	18
	MWμL	1	5
4.5	μL	3	20
	MWμL	1	5

III APPLICATIONS

A Driver Tree

The driver trees in Figs. 6(a) and 6(b) illustrate the drive capability of hybrid systems. Often, because of packaging and related transmission considerations it is desirable to use a number of cascaded inverters rather than a single high-powered buffer to achieve the required fan-out. The tree in Fig. 6(a) consists of 21 μL elements dissipating a total of 315 mW and requiring 30 nsec to transmit a pulse. Figure 6(b) shows a mixed-family, 17-element driver tree. Because the MWμL 4-input gate used as the second stage contains an inverter, this tree can transmit a pulse of the same polarity as the all-μL tree in 60 nsec with a power dissipation of 47 mW — which is only one-seventh the power required by the single-family driver tree.

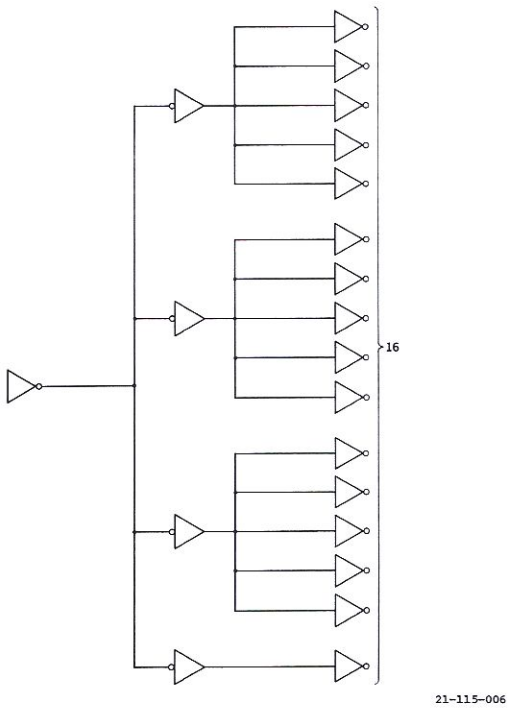

FIG. 6a. μL inverter driving μL inverters.

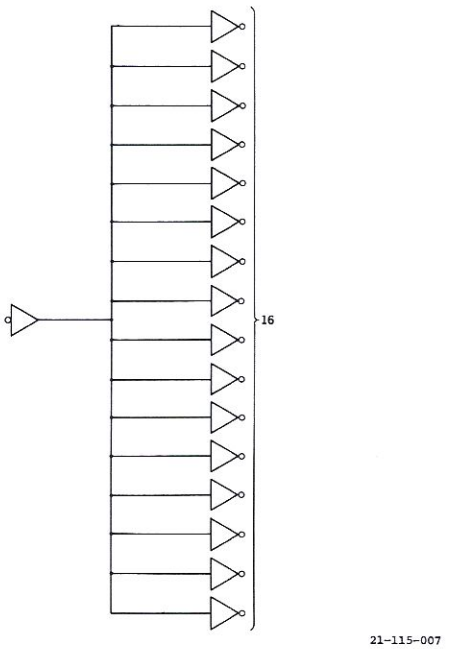

FIG. 6b. μL inverter driving MWμL inverters.

A Counter-Decoder

Figures 7(a) and 7(b) give two examples of a 16-bit counter-decoder—one constructed with μL elements alone and the other with a hybrid system. Two such counter-decoders are commonly used to feed bits of information to a 256-bit matrix required in many magnetic core, drum, tape, or card memory systems. In the single-family approach shown in Fig. 7(a), the fan-out available from each side of each J-K is five μL loads.[3] Of these, two from one side must drive the subsequent J-K. Therefore, to obtain the required fan-out of eight μL loads from each side of each J-K to drive eight loads in the decoding stage, a total of eight buffer elements must be inserted. If a pulse inversion is required from the decoding stage, eight dual 2-input gates must be added. Thus a total of 36 cans would be required to do the job using μL alone, with a total power consumption of 1,020 mW.

In the mixed system shown in Fig. 7(b), the two sides of the J-K's can feed 16 MWμL loads. Of these, five from one side are required to drive the subsequent J-K element. This leaves 11 of the 16 from one side to feed the required 8 loads. The 16 remaining drive the other side. Since each of the MWμL 4-input gates in the decoding stage contains an inverter, it can provide a pulse inversion if desired. Thus a total of only 20 elements with a power consumption of 364 mW are needed—a reduction of over 70 percent in power and 44 percent in cans obtained by combining the two families. Table IV compares the power and element requirements of each of the two systems in Figs. 7(a) and 7(b).

Table IV

COMPARISON OF SYSTEMS

System	Element Type	No.	Power Dissipation (mW)
μL Only	J-K Flip-Flop	4	300
	Buffer	8	240
	4-Input Gate	16	240
	Dual 2-Input Gate	8	240
Total		36	1020
Mixed μL & MWμL	J-K Flip-Flop	4	300
	MWμL 4-Input Gate with Inverter	16	64
Total		20	364

[3] Each side of a J-K will drive 16 MWμL loads and therefore 5 μL loads.

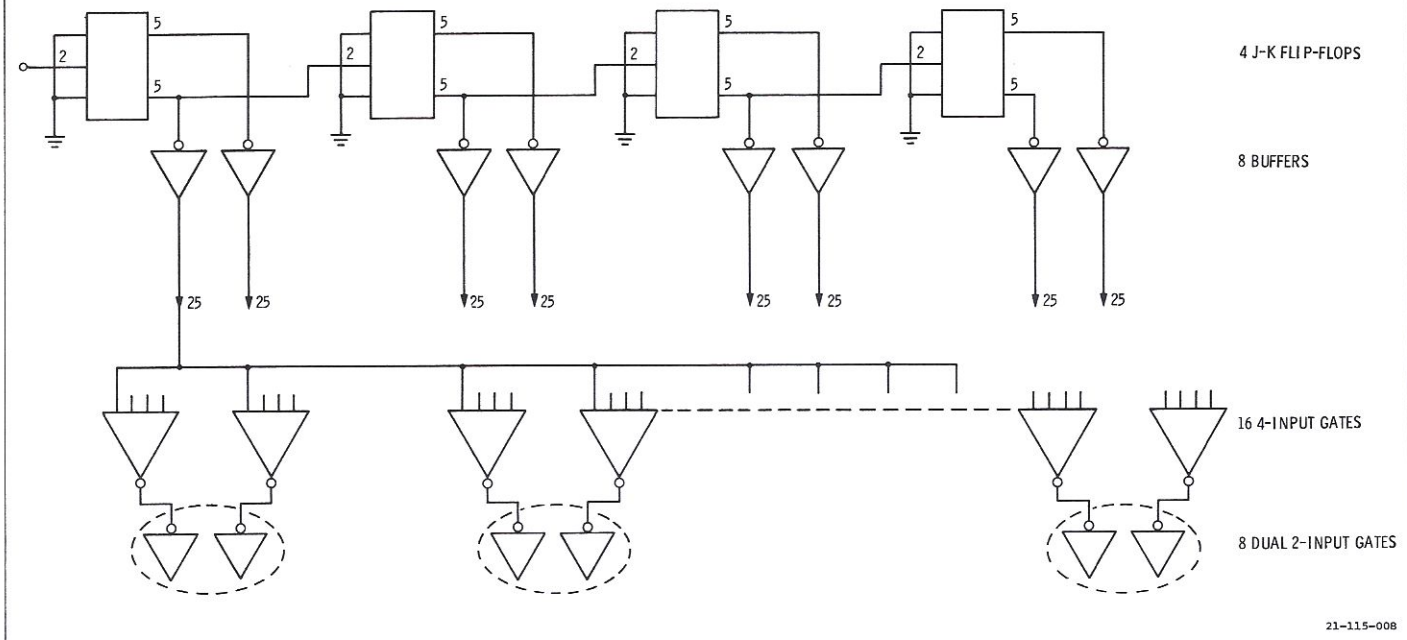

FIG. 7a. Counter-decoder, μL driving μL.

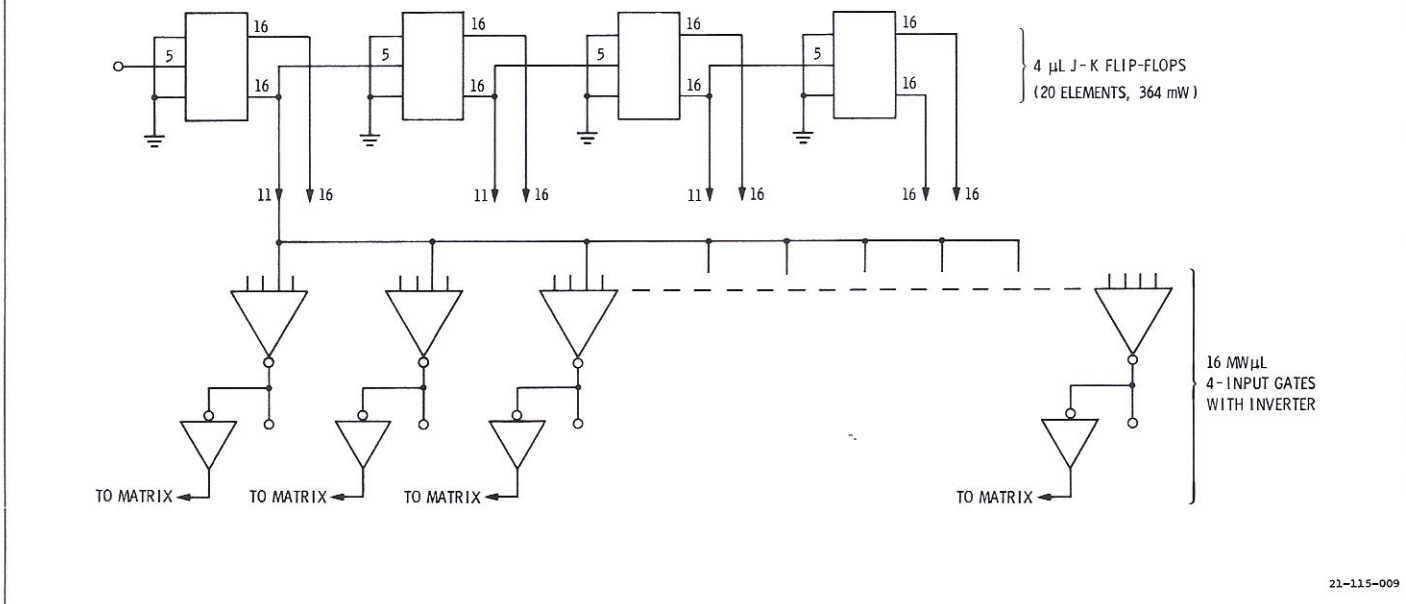

FIG. 7b. Counter-decoder, μL driving MWμL.

IV CONCLUSIONS

The same principles apply to the design of integrated digital systems. By studying the electrical characteristics of the various microcircuits on the market today, the designer can choose the best combination for each logic function, just as he would choose individual components. In this way he can tailor each circuit to rigid requirements for fan-in, fan-out, speed, power, etc., so that the final computer system meets whatever specifications he has chosen. Furthermore, he can design this improved computer with minimum integrated circuit parts and interconnections, thus increasing reliability and reducing the final price.